Determination of Thermal Conductivity of Metals

إعداد

عثمان محمود شريف

جامعة الموصل

كلية الهندسة الميكانيكية

المرحلة الثالثة

شعبة B

Introduction

In this experiment we will evaluate the thermal conductivity of copper and Stainless Steel experimentally and find the temperature distribution for copper and Stainless Steel bars having the same constant cross-sectional area.

The transfer of heat is normally from a high temperature object to a lower temperature object. Heat transfer changes the internal energy of both systems involved according to the First Law of Thermodynamics.

Conduction is heat transfer within a material without any motion of the material as a whole. If one end of a metal rod is at a higher temperature, then energy will be transferred down the rod toward the colder end because the higher speed particles will collide with the slower ones with a net transfer.

Specimens:

Material	Diameter (mm)	Length (mm)	Distance between thermocouple holes (mm)	Distance between end and nearest thermocouple holes (mm)
Copper	25	64	50	7
Stainless Steel	25	38	25	6.5

Readings:

T_1	T_2	T_3	T_4	T_{wi}	T_{wo}	Vol	time
193	186	145	91	21	27	$40x10^{-6}$	36

Theoretical background:

For steady one dimensional heat conduction in the axial direction through specimens, heat flow rate as given by:

$$q = \frac{KA\Delta T}{L} \quad \text{.........................(1)}$$

Where K = thermal conductivity of the specimen.
A = cross sectional area of the specimen.
L = distance between the thermocouples holes.
ΔT = temperature difference indicated by the thermocouples inserted into the specimen.

Heat flow rate, q, may be calculated from:

$$\dot{q} = \dot{m}\, Cv\, (\Delta \mathrm{T})_w \quad \text{.....................(2)}$$

where m = water flow rate through the calorimeter.
C_v = specific heat of water.
$(\Delta T)_W$ = temperature rise of water across the calorimeter.

Using equation (1) and (2) thermal conductivity of the specimens may be determined. Neglecting the contact resistant between the specimens is given by:

$$q = \frac{T_a - T_b}{\frac{L_1}{AK_1} + \frac{L_2}{AK_2}} \quad \text{......................(3)}$$

Where T_a = temperature at the heating element end.
T_b = temperature at the lower specimen end.
A = cross sectional area of the specimen.
L_1 = length of long specimen.
K_1 = thermal conductivity of long specimen.
L_2 = length of short specimen.
K_2 = thermal conductivity of short specimen.

T_a and T_b are determined by extrapolating the temperature readings in the specimens.

Calculation of Thermal Conductivity for Copper and Stainless Steel

$$\dot{q} = \dot{m}\, Cv\, (\Delta \mathrm{T})_w$$

$$\dot{m} = \frac{Vol}{t} = \frac{40x10^{-4}\ x\ 1000}{36} = 1.111\ x\ 10^{-3}$$

$$\dot{q} = 1.111\ x\ 10^{-3}\ x\ 4.2\ \ 1000\ \mathrm{x}\ (27 - 21) = 28\ \mathrm{W}$$

$$\mathrm{q} = \frac{KA\Delta T}{L}$$

$A = \pi r^2 = \pi(25/2)^2 = 4.9087\ x\ 10^{-4}$ Area for Both Copper and Steel

For Copper: $\mathrm{K} = \frac{q\ x\ L}{A\ x\ \Delta \mathrm{T}} = \frac{28\ x\ 50\ x\ 10^{-3}}{4.9087\ x\ 10^{-4}\ x\ (193-186)} = 407.4398517\ \frac{W}{m}.c$

For Stainless Steel: $\mathrm{K} = \frac{q\ x\ L}{A\ x\ \Delta \mathrm{T}} = \frac{28\ x\ 25\ x\ 10^{-3}}{4.9087\ x\ 10^{-4}\ x\ (145-91)} = 26.4079\ \frac{W}{m}.c$

Comparison of thermal conductivity between the calculated results and given Text Book data:

Specimens	**Calculations**	**Text Book Data***
Copper	$407.4398517\ \frac{W}{m}.c$	$385\ \frac{W}{m}.c$
Stainless Steel	$26.4079\ \frac{W}{m}.c$	$17\ \frac{W}{m}.c$

*Textbook Data is taken from Holman Heat Transfer 10th Edition

Calculation of T_a and T_b

We can calculate T_a and T_b by extrapolating the temperature readings in the specimens using the **Temperature – Length** Diagram.

$$\frac{T_a - 193}{193 - 186} = \frac{7}{50} \longrightarrow T_a = 193.98° \text{ C}$$

$$\frac{T_b - 91}{91 - 145} = \frac{6.5}{25} \longrightarrow T_a = 76.96° \text{ C}$$

Calculation of heat flow rate using Egn.3

$$q = \frac{T_a - T_b}{\frac{L_1}{AK_1} + \frac{L_2}{AK_2}}$$

$$q = \frac{193.98 - 76.96}{\frac{64 \text{ x } 10^{-3}}{4.9087\ x\ 10^{-4}\ x\ 407.4398} + \frac{38 \text{ x } 10^{-3}}{4.9087\ x\ 10^{-4}\ x\ 26.4079}}$$

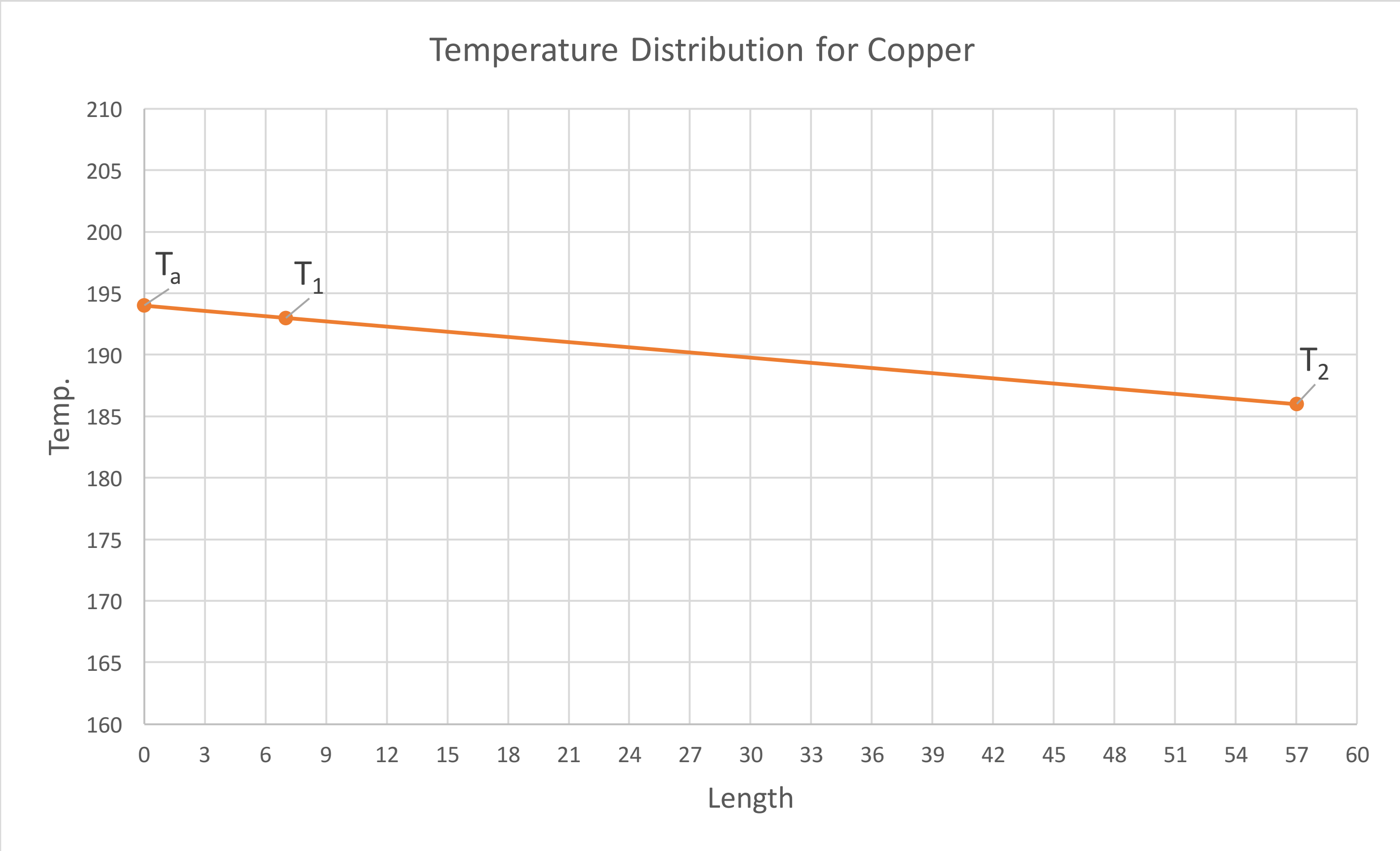
$$q = 36\ W$$

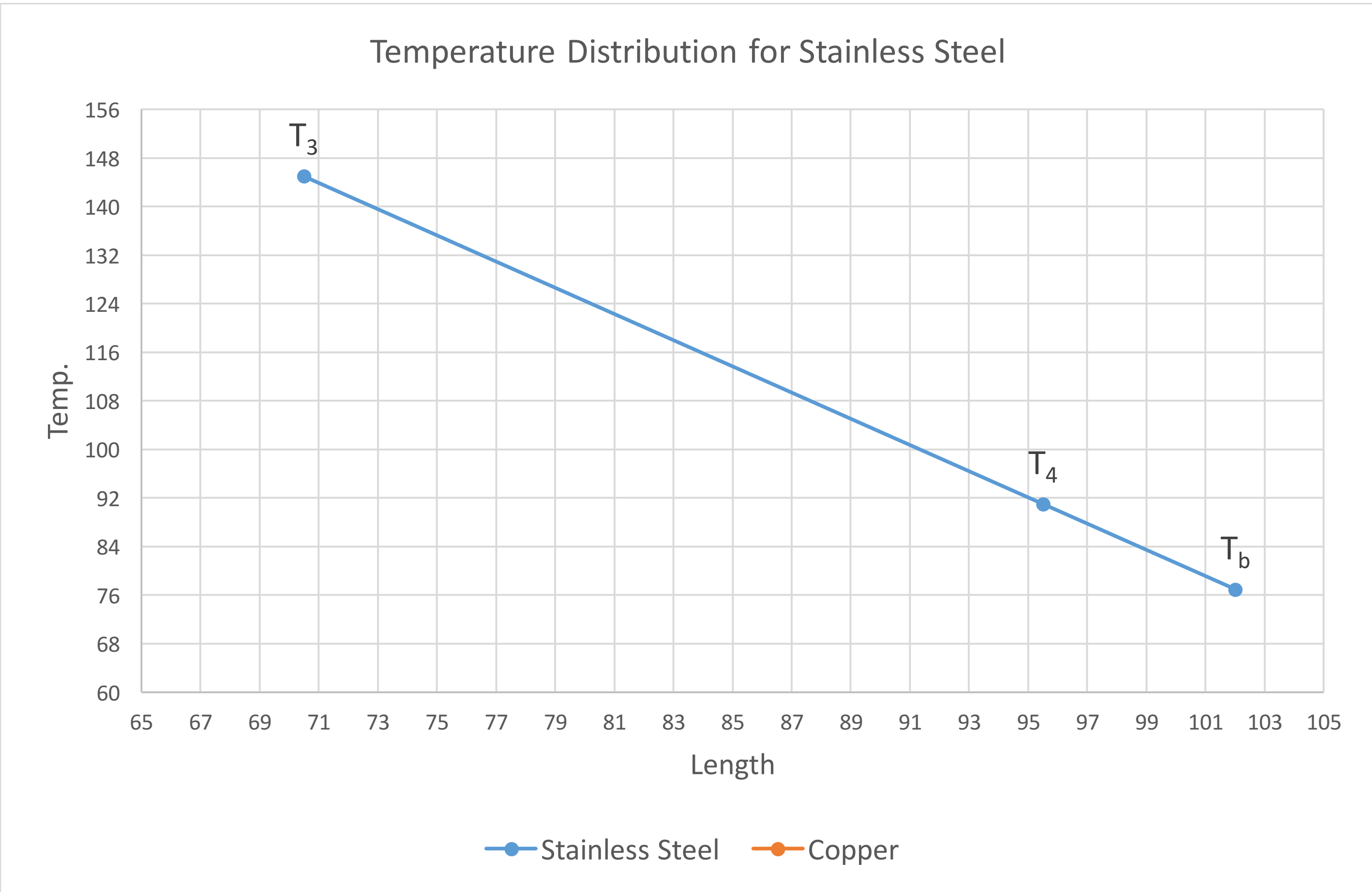
Comparison of Heat transfer rate between Egn.2 & Egn.3:

Equation number	Heat Transfer rate (**q**)	Notes
2	28 W	**q** was calculated for the points where the thermocouples measured the temp. taking the length 25mm and 50mm for Steel and Copper respectively
3	36 W	**q** was calculated for the points T_a & T_b which we calculated for the surfaces of the two elements. taking the length 38mm and 64mm for Steel and Copper respectively

Discussion

As we see form the tables comparing the thermal conductivity for Copper and Stainless Steel, the results where similar to that given in the Text Book with a small error, we can measure the ratio or percentage of the error of the apparatus by comparing the exact data from the Text Book with the results that we calculated to determine the accuracy of the apparatus.
Another source of difference between the calculated and given thermal conductivity is because the bar may not be made of pure materials.


Temperature Distribution for Copper
Temp.
Length
Ta
T1
T2
210
205
200
195
190
185
180
175
170
165
160
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
54
57
60


Temperature Distribution for Stainless Steel
Temp.
Length
T3
T4
Tb
156
148
140
132
124
116
108
100
92
84
76
68
60
65
67
69
71
73
75
77
79
81
83
85
87
89
91
93
95
97
99
101
103
105
Stainless Steel
Copper